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Harry L. Dale
Oklahoma City
Okla.

[*Frontispiece.*]

PLATE I.—SURVEYING UNDER DIFFICULTIES.

TOPOGRAPHIC SURVEYING.

INCLUDING

GEOGRAPHIC, EXPLORATORY, AND MILITARY MAPPING,

WITH HINTS ON

CAMPING, EMERGENCY SURGERY, AND PHOTOGRAPHY.

BY

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PREFACE.

THIS book has been prepared with a view of bringing together in one volume the data essential to a comprehensive knowledge of topographic surveying. It has been my aim to cover the varied phases of all classes of surveys which are made with a view to representing on maps information relative to the features of the earth's surface. The methods elaborated are chiefly those which have been developed in recent years by the great government surveying organizations and by such few private corporations as have kept in touch with the most modern practice; but I have endeavored to go beyond these, and, guided by personal experience, to adapt them to the most detailed topographic as well as to the crudest exploratory surveys. The hope is entertained, therefore, that the engineer who may be called upon to conduct an exploratory survey in an unknown region, or to make a detailed topographic map as a preliminary to construction, will find herein descriptions and examples of the methods he should employ, the essential tables for the computation of his results, and hints which will guide in the equipment of his party.

I have sought to avoid any detailed description of those instruments or methods which are elaborated in works on general surveying. The volume is devoted practically to higher surveying, and presupposes a knowledge of all the more elementary branches. At the same time, many of the

subjects treated are essentially elementary, and these are briefly described, in order that all the facts which the topographer must know and all the formulas and tables which he must have at hand in the field may be brought together. An effort has been made to present the subject in the most practical form. Accordingly, care has been taken to avoid an elaboration of the mathematical processes by which the various formulas have been derived, as they are to be found in detail in several well-known treatises to which textual reference is made. To give more immediate aid to the working surveyor, examples of the various computations are presented, as are illustrations of the instruments, methods, and resulting maps from surveys actually executed.

The mode of presentation is not that usually followed in such works. Instead of describing the instruments or their uses independently, each is described in that portion of the text in which its employment in field surveying is most prominently mentioned. The tables are not brought together at the end of the volume, but each is placed in that portion of the text which relates to its use. The object is to produce a handy reference-book for use in the field, as well as a text-book for guidance in college instruction. It is believed that, by this arrangement, if a topographer in the midst of his field-work desires information on a special point, it can be found, with accompanying examples and tables, gathered together in one chapter or clearly indicated by cross-references. Again, the method of treatment usually followed in works of this class consists in, first, a description of the astronomic methods on which general map surveys must be based, and then a description of primary triangulation as a basis for the detailed topographic surveys which are finally described. I have reversed this order and have adopted the more natural method of commencing with the simplest operations and advancing gradually towards the most complex and refined. Each subject is treated in the same manner. It is believed that the

work has thus been made especially useful to the inexpert topographer and the student.

The volume consists, in fact, of three separate books or treatises: (1) Topographic Surveying, (2) Geodetic Surveying, and (3) Practical Astronomy. The first has been subdivided into three parts: Plane Surveying, Hypsometric Surveying, and Map Construction; and these are preceded by a preliminary characterization of the relations existing between topographic, geographic, and exploratory surveys. This latter distinction is essentially arbitrary, as all are of a kind, and differ only in degree of detail and the consequent speed and generalization in procuring the field results. The general subject of Geodetic Surveying has been subdivided into Terrestrial Geodesy and Astronomic Geodesy, and the treatment of these differs but slightly in method of arrangement from that usually pursued. Part VII is devoted to such practical hints as it is believed will essentially aid those who have the organization and command of camping parties.

I am especially indebted to the courtesy of Professors Ira O. Baker, J. B. Johnson, and John F. Hayford for the use of numerous electrotypes and plates from their well-known works on surveying and geodesy; and to the Secretary of the American Society of Civil Engineers for electrotypes of illustrations in articles by me. I am also indebted to Messrs. W. & L. E. Gurley, Young & Sons, and G. N. Saegmüller for electrotypes of instruments illustrated in their catalogues. I have used freely the excellent Manual of Topographic Methods of the U. S. Geological Survey, written by Mr. Henry Gannett; in a few instances I have copied verbatim examples contained therein, and I desire to express appreciation of his courtesy, and of that of the Director of the U. S. Geological Survey in extending this privilege. To the latter I am also indebted for an opportunity to procure the colored illustrations published herewith, which were printed from the admirable copper-plates of the U. S. Geological Survey. Spe-

cifications and several illustrations of tents and other camp equipage were obtained through the courtesy of the Quartermaster-General of the U. S. Army. For much in the chapter on Photography I am indebted to Lieut. Samuel Reber's Manual of Photography and to E. Deville's Photographic Surveying.

Finally, I desire to express appreciation of the assistance I have received in editing manuscript and proof from many coworkers on the U. S. Geological Survey, more particularly from Messrs. W. J. Peters, S. S. Gannett, and E. M. Douglas on the subjects of geodesy and astronomy; E. C. Barnard and A. H. Thompson on topographic surveying; C. Willard Hayes and G. K. Gilbert on topographic forms and definitions; N. H. Darton on photography; and to Mr. W. Carvel Hall for assistance in reading proof. Two lists of works of reference are published, on pages 490 and 809, in which are cited the titles of all those works to which the reader is referred for further details. From nearly all of these some example or illustration has been obtained.

H. M. W.

WASHINGTON, D. C., Feb. 22, 1900.

PREFACE TO SECOND EDITION.

IN preparing this second edition no radical changes have been made in any chapter. Numerous minor changes and corrections have been made, however, chiefly in the nature of citations of new practices or correction of old. This is particularly true of the subject of Projections, which is better illustrated, that of Precise Leveling, and the bringing up to date of tables of Polaris Observations.

H. M. W.

WASHINGTON, D. C., Feb. 20, 1905.

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PART I.

TOPOGRAPHIC, GEOGRAPHIC, AND EXPLORATORY SURVEYING.

CHAPTER I.

KINDS OF MAP SURVEYS.

1. **Classes of Surveys.**—Surveys may be grouped under three general heads:

1. Those made for general purposes, or information surveys.
2. Those made for jurisdictional purposes, or cadastral surveys.
3. Those made for construction purposes, or engineering surveys.

Information surveys may be exploratory, geodetic, geographic, topographic, geologic, military, agricultural, magnetic, or hydrographic. Geodetic surveys are executed for the purpose of determining the form and size of the earth. They do not necessarily cover the entire surface of the country, but only connect points distant from each other 20 to 100 miles. Topographic and geographic surveys are made for military, industrial, and scientific purposes. To be of value they must be based upon trigonometric or triangulation surveys, but not necessarily of geodetic accuracy.

The mother map, or that from which all others are derived, is the topographic map. This is made from nature in the field

by measures and sketches on the ground. It is the original or base map from which can be constructed any variety of maps for the serving of separate purposes. The historian may desire to make a map which will indicate the places upon which were fought great battles, or on which are located the ancestral estates of historic families. The geologist may desire to indicate the location of certain rock formations. The promoter of railways or other engineering works may desire to represent the route of his projected road or the location of city water-supplies or real-estate subdivisions. For these several purposes the topographic or base map furnishes the original data, or foundation, on which can be indicated, in colors or otherwise, any special class of information.

Cadastral surveys define political and private property boundaries and determine the enclosed areas. Such surveys are executed for fiscal and for proprietary purposes, and their value depends upon the degree of accuracy with which they are made. A cadastral survey is not necessarily based upon triangulation and may be only crudely executed with compass and chain. To thoroughly serve its purpose, however, it should be based on geodetic work of the greatest refinement. It does not necessarily cover the entire area enclosed, but only points and lines which mark the boundaries.

Engineering surveys are executed in greater detail than any of the above. They may preferably follow some of them and are preliminary to the construction of engineering works. They are conducted with such detail as to permit the computing of quantities of materials to be moved and the exact location of the various elements of the works which are to be constructed. Engineering surveys may be made for the construction and improvement of military works, as forts, navy yards, etc.; for constructing routes of communication, as roads, electric lines, canals; for reclamation of land, as irrigation and swamp surveys; for the improvement of natural waterways, as river and harbor sur-

veys; or for the improvement of cities, as city water-supply and sewage disposal.

2. Information Surveys.— All surveys have a twofold purpose:

1. To acquire certain information relative to the earth; and

2. To spread this among the people.

The acquirement of the information is the field survey. The dissemination may be in the form of manuscript, illustrations, or sketch maps, as in the case of exploratory surveys; of a map only, as in the case of topographic surveys when the map embodies the whole result; or it may be a combination of the two, as in the case of geographic surveys.

In addition to the above primary classes of information surveys are the numerous minor differences in the method of field-work, including the instruments used, the degree of care in obtaining the information, and the mode of recording the results in notes or maps. The instrumental work of *exploratory surveys* is usually of the crudest and most haphazard kind, the observations having to be taken and the notes recorded incidentally and by such means and at such time as the primary necessities of the expedition, those of moving forward over the route traversed, will permit. Moreover, from the necessity of the circumstances such surveys are rarely homogeneous, never covering completely any given area; else they would cease to be exploratory. Being disconnected, they are fixed from time to time with relation to the earth by such astronomic observations as will frequently check the interrupted route surveys in relation one to the other.

Topographic and geographic surveys differ essentially from exploratory surveys, but from each other only in minor details of scale, degree of representation of relief, and the note taken of the sphericity of the earth. *Topographic surveys* are generally executed on so large a scale and with such

care and detail that account need rarely be taken of the sphericity of the earth in plotting the resulting map, and they are therefore based on geodetic data only as they merge into geographic surveys. Moreover, all important natural and artificial features may be represented on the resulting map because of its large scale.

Geographic surveys merge imperceptibly, on the one hand, into topographic surveys, as the scale of the latter becomes so small and the area depicted on a given map sheet so large that the shape of the earth must be considered. On the other hand, they may be plotted on so small a scale and the relief be depicted by such approximate methods that they merge imperceptibly into exploratory surveys, being practically of the same nature as the latter excepting that they cover a given area in its entirety.

3. Topographic Surveys. — A topographic map is one which shows with practical accuracy all the drainage, culture, and relief features which the scale of representation will permit. Such scale may be so large and the area represented on a given map sheet be so small that the control for the field surveys will be procured by means of plane and not of geodetic surveying. On the other hand, the scale may be so small and the area represented on the given map sheet so large as to require control by geodetic methods.

The mistake is often made of assuming that a topographic map is special and not general. It is general, as it is not made for the purpose of constructing roads and highways, though it becomes a very valuable aid in their projection; nor is it made for the purposes of reclaiming swamp-land or irrigating arid land, but it furnishes general information essential to a preliminary study and plan for their improvement. The outcome of a topographic survey being a topographic map, it should be judged by the map, and the map should be judged by the manner in which it serves the general purpose. Above all, of two maps or works of any kind

made for the same purpose and serving that purpose equally well, that the cheaper one is the better is a well-recognized principle of engineering.

In the prosecution of a general topographic survey only such primary points should be determined geodetically as are essential to the making of the map. About one such point per one hundred square miles is a fair average for a one-mile to one-inch map. Such spirit-level bench-marks should be set and recorded as are obtained in carrying bases for levels over the area under survey. On the above scale about one bench to five square miles is a fair average.

4. **Features Shown on Topographic Maps.**—The features exhibited on topographic maps may be conveniently grouped under the three following heads:

1. The hydrography, or water features, as ponds, streams, lakes.

2. The hypsography, or relief of surface forms, as hills, valleys, plains.

3. The culture, or features constructed by man, as cities, roads, villages, and the names printed upon the map.

In order that these various features may be readily distinguishable and thus give legibility to the map, it is usual to represent the hydrography in blue, the relief in brown, and the culture in black. In addition to this, wooded areas may be indicated in a green tint.

The object of a topographic survey is the production of a topographic map. Hence the aim of the survey should be to produce only the map; neither time nor money should be wastefully expended in the erection or refined location of monuments; the demarkation of public or private boundary lines; or the establishment of bench-marks beyond such as are incidental to the work of obtaining field data from which to make the map. The erection, location, and description of boundary marks is the special work of a property or cadastral survey. The erection, description, and determination of

monuments and bench-marks as primary reference points is the work of a geodetic survey. The determination of many unmarked stations for map-making purposes is the work of a topographic survey.

5. **Public Uses of Topographic Maps.**—For the purposes of the *Government or State* good topographic maps are invaluable. They furnish the data from which the congressman or the legislator can intelligently discover most of the information bearing directly upon the problem in hand, and they give committees great assistance in their decisions as to the need of legislation. If a River and Harbor bill is before Congress, or a bill relating to State Canals before the Legislature, by an inspection of such maps the slopes of the country through which the canal is to pass or in which the improvements are to be made may be readily ascertained. The sources of water-supply for a canal or river may be accurately measured on such a map and their relation to the work in hand intelligently ascertained.

If the *War Department* of the Government or the Adjutant-General's Office of the State desires to locate an arsenal, encampment ground, or other military work, or, above all, if it is to conduct active military operations in the field, such maps serve all the preliminary purposes of the best military maps. With the addition of a very little field-work during war times, such as the indication of ditches, fence lines, outbuildings, etc., on the mother or topographic map, a perfect military map may be obtained.

For the *Post-office Department* or private stage, express, or telephone companies, such maps furnish the basis on which an accurate understanding can be had of contracts submitted for star or other routes for carrying the mails or packages. As these maps show the undulations of the surfaces over which roads pass, their bends and the relative differences in length, the difficulties in travel on competing roads can be readily ascertained from them.

The *Land Departments* of the Government and State can discover on such maps not only the outlines of the property under their jurisdiction, but its surface formation. *Forestry Boards* can see indicated upon these maps the outlines of the various wooded areas, besides the slopes of the lands on which these woods are situated, their relation to highways of transportation, railways, or streams, and the slopes to be encountered in passing through the woods on these highways.

The *Legal department* of the Government or State finds these maps of service in discussing political or property boundary lines, in ascertaining within what political division crimes are committed, or individuals reside with whom the officers of the law desire to communicate. It is difficult to see how any systematic or economical plan of road improvement can be advantageously made without the knowledge of existing grades, the physiography of the district through which the roads pass, and the location of quarries, which such maps present.

The whole system of making successive *special surveys* or maps for every new need is one of the most wasteful in our present public practice, nor can it be otherwise until one survey shall be made that answers all important official uses. The amount of money that has been expended in making small maps of numerous cities and villages would have mapped, on a general scale, many times the area of the country. Even when we have these special maps they do not fully answer the purpose for which they were intended, as they only show the small area included within the immediate plan of operations. The value of a stream for economic purposes cannot be fully ascertained by an examination of the stream at the point from which it is to be used, but the drainage basin from which it derives its supply should be surveyed, and its area and slopes be known. A good topographic map not only shows the relations between the natural and artificial features in the immediate neighborhood under consideration, but it shows the relations of these to the surrounding country.

6. Degree of Accuracy Desirable in Topographic Surveys.—It is difficult to set any standard for the amount of detail which the topographer must sketch on his map, or the amount of control which must be obtained for the checking of this detail. A topographic map may be so made as to serve many useful purposes and yet be almost wholly a sketch, scarcely controlled by mathematical locations. The same territory may be mapped on the same scale with little improvement in the quality of representation of topographic form and yet the work be done with such detail and accuracy and such amount of control as to make it useful for all practical purposes to which its scale adapts it.

With these facts clearly in view, it is evident that explicit *instructions to the topographer* are a practical necessity. Unlike any other surveyor the topographer must use his own judgment or be guided by instructions regarding the amount of time and money to be spent in obtaining detail and control, since the latitude permissible in mapping the same territory on the same scale varies greatly according to the uses to which the map is to be put. Such instructions should interpret the significance of scale and contour interval, and should cover the technical details of operations as found applicable to conditions and locality (Art. 7). They should also fix the method of making and preserving field-notes. There are a variety of methods of survey, of instruments, and of records which are generally applicable to any case, yet to the expert topographer there is practically only one best way for each, and this can be decided only after he has inspected the country or has otherwise acquired knowledge of its characteristics.

The scale and mode of expressing relief (Art. 191) must be fixed as well as the contour interval, if contours are employed, in order that all the data necessary for the construction of the map on this scale may be obtained. The methods and instruments should be stated in order that those best

suited to the conditions may be selected in the beginning. The mode of record should be fixed in order that there may be uniformity in the results brought into the office, provided there are various topographers working on the same area. Such instructions are to the topographer what specifications are to the contractor, yet they cannot quite carry the force of law because of the unforeseen exigencies which may arise and which require departure from fixed instructions in accordance with the best judgment of the topographer.

In topographic mapping it is sometimes desirable to make hasty *preliminary or reconnaissance maps* of a region in order that some information of the area may be immediately obtained. Such maps are practically sketches covering an extensive area and without adequate framework of control, yet they contain most of the information required in the early development of the region. The error has too frequently been made of giving such maps the ear-marks of accuracy by representing the relief by numbered contours. In this they are misleading. Contours indicate precision and should justly be taken as accurate within the limits of the map scale. As has been aptly stated by Mr. J. L. Van Ornum, "accuracy is expected where exactitude is shown, and the conclusion is just that inaccuracy in representation is inexcusable." Where for any reason the desired accuracy cannot be attained for lack of the proper control, the resulting map is merely a sketch-map, and relief should be indicated not by contours but by hachures or by sketched contours; that is, lines in contour form, but disconnected and unnumbered. Such sketch-maps are useful as representations of topographic form, but are valueless as base-maps on which to plan great public improvements, the inception of which is so closely connected with topographic surveys.

A topographic map well executed is, to quote Captain George M. Wheeler, "the indispensable, all-important survey, being general and not special in character, which under-

lies every other, including also the graphic basis of the economic and scientific examination of the country. This has been the main or principal general survey in all civilized countries. The results of such a survey become the mother source or map whence all other fiscal examinations may draw their graphic sustenance." Such a characterization of a topographic survey can apply only to one accurately made and on which every feature represented is as accurately shown as the scale of map warrants.

In *planning a topographic survey* the controlling factor of the scale must always be kept clearly in mind, as this is the ultimate criterion which decides the method of survey and the amount of time and money to be expended in its execution. The underlying law of topographic mapping is that applied to other engineering works, namely, no part of the construction, nor any part of the survey, should be executed with greater detail or at greater expense than will permit it to safely perform the duties for which it is intended. Thus, in mapping an extended area, traverse methods alone for *horizontal control* are insufficient unless performed with the greatest exactitude. The primary triangulation on which such a survey is based should be no more accurate than will permit of plotting the points with such precision that they shall not be in error by a hair's breadth at the extreme limit to which the triangulation is extended. The secondary triangulation should be executed with only such care as will permit of plotting without perceptible error on the scale selected and within the limits controlled by the nearest primary triangulation points. Simpler methods of securing horizontal control may be adopted for the minor points within the secondary triangulation, and these methods, be they by plane-table triangulation (Chap. IX) or by traverse (Chap. X), need be nothing better than will assure the plotting of the result without perceptible error and within distances controlled by the nearest secondary triangulation points. Finally, minor details may be obtained by

the crudest methods of traverse, range-finding, pacing, or sketch-board (Arts. 81, 116, 95, and 61), providing that the distances on the map over which such methods are propagated shall be so small as to warrant their not being perceptibly in error within the limits of the controlling points of the next higher order.

As with the horizontal control so with the *vertical control*, no more time should be expended or precision attempted in determining elevations than are necessary to obtain the data essential to the mapping of the relief accurately to the scale limit. Where relief is to be represented by contours of a small interval and on a large scale, or where the slopes of the country are gently undulating or comparatively level, the leveling must be of a high order that the contours may be accurately placed in plan. In country having slopes as gentle as 5 to 10 feet to the mile, a difference of a few feet in elevation may mean that distance in error in the horizontal location of the contour if the elevations are not determined with accuracy. On the other hand, in precipitous mountain country much less care is necessary in the quality of the leveling, since a large error in vertical elevation may be represented in plotting by the merest fraction in horizontal plan. For a large contour interval in country of moderate slopes less accuracy is essential in the determination of the elevation. For contours of 20 feet interval errors of elevation varying from 5 to 20 feet or more may be made, depending upon the steepness of the slope and the consequent nearness in horizontal plan of one contour to the next. The same ratio applies to greater contour intervals. Therefore the methods pursued in determining the elevations should begin with a careful framework of spirit-leveling (Art. 129), and the amount of this should be only so great as to insure that the dependent levels of less accuracy shall not be so far in error as to be appreciable for the scale and contour interval selected and for a given slope of country. Based on these spirit-levels

rougher elevations by vertical angulation with stadia (Art. 102) or by trigonometric methods (Art. 159) may be employed, and tied in between these may be elevations by aneroid (Art. 174), the latter being checked at intervals sufficiently frequent to assure that the resulting elevations shall not introduce appreciable errors in the location of contours.

The same rules should apply to the frequency with which vertical control points are determined. These should be so close together for the scale of the map and for the contour interval selected that in connecting them by eye in the course of the sketching no error appreciable on the scale shall be introduced. Any map, the best obtainable, is but a sketch controlled by locations. No one would undertake to determine the elevation and horizontal plan of every point on a contour line. Control positions on contours are only determined with sufficient frequency to insure comparative accuracy in connecting them. Bearing on this same point is the fact that such connection by sketching can undoubtedly be done with greater accuracy on the plane-table board with the terrane in view than from notes platted up in office or from photographs or profile drawings.

Where relief is to be represented by hachures or broken sketch contours, precision in absolutely fixing the vertical element is of the least moment. It is generally desirable in making such maps to write approximate altitudes at prominent points, as stream junctions, villages, or mountain summits, but the chief desideratum is relative differences in elevation in order that the number of the sketched contours and their frequency, or the degree of density of the hachuring, may give an index to the amount of relief.

7. **Instructions Relative to Topographic Field-work.**—The following instructions are those issued by the Director of the United States Geological Survey for the guidance of topographers in the field:

1. At least two primary triangulation points or a primary control line

1. All primary triangulation points and primary control lines should be platted on each atlas sheet previous to commencing field-work.

2. All existing map material should be diligently sought for; such of this as may be of value, as public-land plats, railroad, water-supply, city, Coast Survey, Army Engineer, or other public or private material, should be carefully compiled. If on field inspection this proves adequate, it should be brought up to date and incorporated in the field sheets.

3. On each atlas sheet, in addition to primary levels, such other elevations should be obtained instrumentally that aneroids when used need never be left without a check elevation for distances exceeding 2½ to 3 miles. These control elevations may come from profiles of railroads, from spirit-levels or from vertical angulation.

4. Plane-table triangulation must be conducted on the large sheets, and it is desired that as fast as intersections are obtained by the topographer the vertical heights of stations and intersected points should be computed.

5. In conducting plane-table triangulation, as many prominent features as possible, including hilltops, churches, and houses, should be intersected in order to furnish connections with the traverse work, while gaps or passes and salients on ridges should also have their positions and elevations determined from the plane-table stations.

6. Secondary topographic control must precede topographic sketching and the filling in of minor details of the map.

7. Field sheets must be as few in number and as large as the character of the topography will permit, and all main control must be adjusted thereon; this to be done before the filling in of minor detailed sketching is commenced. These minor details may be obtained by traverse on separate sheets, but must at once be transferred to and adjusted on main field sheets, so that no uncompleted spaces shall be left on them in the field.

8. The stage of water in rivers to be shown on the topographic maps is to be that which exists during the greater portion of the year and represents the normal condition of the stream. When any other condition is represented an explanatory note giving stage and date should be inserted in the legend.

9. The topographer in charge will be held responsible not only for the quality of the topographic work but also for the quality and management of the spirit-leveling done under his direction, and for the location and marking of the bench marks, each of which he should endeavor to examine personally. Standard bench marks should be indicated on field sheet.

10. Only so much of the field sheets should be inked in the field as can be done with sufficient care to permit of their being accepted as final drawings and of their being directly photographed or photolithographed (except where land-survey plats are used as field sheets). Accordingly, only such

inks should be used as will photograph readily—mixed burnt sienna for contours, black for culture, and mixed Prussian blue for drainage.

11. A full record must be made on the title-page of each notebook, stating character of work, locality, atlas sheet, and date of record; also name of topographer and maker of notes.

12. Plats, on a large scale, should be made or obtained of all large cities, showing the streets and houses in detail.

13. The determination and spelling of names of streams, mountain peaks, villages, and other places of note should receive particular attention.

14. Plane-table stations must be numbered consecutively with Roman numerals. If the station has been sighted before occupation, the station number must be followed by the number of the sight to it. Sights or points must be numbered by Arabic numerals consecutively; and a point once numbered must always be given the same number whenever recognized. If the points sighted exceed one thousand in number, a capital M shall be written at the head of the number column of the notebook. This rule must be followed by all members of the topographic branch.

15. The standard conventional signs must be used on all plane-table and traverse sheets.

16. The sheets must be inked clearly and carefully, with uniformity throughout, and in such manner as to adapt them for one-third reduction to publication scale. Only such ink should be used as will photograph readily. (See par. 10, above.) Culture should be inked first, and standard conventional signs used.

17. In drawing streams care should be taken that the lines shall not become faint and uncertain near the sources of the streams, and the placing of drainage in every little gully simply to indicate that it may be a watercourse should be avoided. Use the symbol dash and three dots for intermittent streams.

18. In lettering, names parallel to the east or west sides of the sheet should read from the south side. Names of minor importance and figures of elevation should be placed close to the object, on the right and horizontally. The letters, figures, and cross pertaining to a bench mark should be arranged with the letters above and to the left of the cross, and the figures below and to the right.

19. The original drawing of a topographic sheet shall be verified by some competent person in addition to the topographer who compiles it, by comparison with field sheets, and such "proof-reading" shall be recorded on the appropriate form.

8. Elements of a Topographic Survey.—From a constructive point of view a map is a sketch corrected by locations. The making of locations is geometric, that of sketch-

ing is artistic. However numerous may be the *locations* they form no part of the map itself, serving merely to correct the sketch which supplies the material of the map. Every map, whatever its scale, is a reduction from nature and consequently must be more or less generalized. It is therefore impossible that any map can be an accurate, faithful picture of the country it represents. The smaller the scale the greater the degree of generalization and the farther must the map depart from the original. The larger the scale the smaller the area brought together on a given map, and the less it appeals to the eye which grasps so extended a view of nature. There is, however, for the purposes of making information maps, a scale which is best suited to every class of topography, and the best result only will be obtained by selecting the relation of horizontal scale and contour interval which fits the particular topography mapped.

By far the most important work of topographic mapping is the *sketching* (Arts. 13, 15, 17, and 193), and this should be done by the most competent man in the party—presumably its chief. He should not only sketch the topography because of his superior qualifications for that work, but also because the party chief is responsible for the quality of all the work, and only in the sketching, which is the last act in map-making, has he full opportunity for examining the quality of the control and of the other elements of the work executed by his subordinates. The map-sketcher is therefore the topographer, and it is in the matter of generalization or in the selection of scale and the amount of detail which should be shown for the scale selected that the judgment of the topographer is most severely tested. This is the work in which the greatest degree of proficiency can only be attained after years of experience. The topographer must be able to take a broad as well as a detailed view of the country, and to understand the meaning of its broadest features that he may be able best to interpret details in the light of those features (Chap. VI).

It is only thus that he can make correct generalizations, and thus that he is enabled to decide which detail should be omitted and which preserved in order to bring out the predominant topographic features of the region mapped.

The *correctness of the map* depends upon:

(1) The accuracy of the locations;

(2) Their number per square inch of map;

(3) Their distribution;

(4) The quality of the sketching.

The first three of these elements defines the accuracy of the map, and the greatest accuracy is not always desirable because it is not always economical. The highest economy is in the proper subordination of means to ends, therefore the quality of the work should be only such as to insure against errors of sufficient magnitude to appear upon the scale of publication (Art. 6). The above being recognized, it is evidently poor economy to execute triangulation of geodetic refinement for the control of small-scale maps, and, providing the errors of triangulation are not such as are cumulative, the maximum allowable error of location of a point on which no further work depends may be set at .01 of an inch on the scale of publication.

The second condition, the *number of locations* for the proper control of the sketching, is not easily defined. It depends largely upon the character of the country and the scale and uses of the map. Any estimate of it must be based on unit of mapped surface and not of land area. For rolling or mountainous country of uniform slopes or large features (Fig. 4), from 1½ to 3 locations and 2 to 5 inches of traverse per square inch of map should, with accompanying elevations, be sufficient. On the other hand, in highly eroded or densely wooded country (Fig. 34) as many as 3 to 6 locations and 5 to 10 inches of traverse, per inch of map may, with accompanying elevations, be necessary to properly control the sketching. Again, in very level plains country (Fig. 6) less than one lo-

cation and but 2 to 5 inches of traverse, with accurate elevations, will suffice to furnish adequate control.

The same is true of the third element of accuracy, the *distribution of locations*. In rolling, hilly country of uniform slope the control should be obtained chiefly at tops and bottoms and changes of slope. The same is true of heavy mountains, excepting that all summits and gaps on ridges must be fixed, as well as all changes in side slopes and a few positions distributed about the valley bottoms. In flat plains the positions determined should be locations on the contours themselves and at changes in their direction. In highly eroded regions locations of all kinds should be distributed with considerable uniformity, so as to control every change of feature or slope.

The fourth element, the *quality of the sketching*, depends wholly upon the artistic and practical skill of the topographer—in other words, upon his possession of the topographic sense, which may be described as his ability to see things in their proper relations and his facility in transmitting his impressions to paper. This is by far the most important and difficult requirement to meet, and one which takes a longer apprenticeship on the part of the topographer than all the others combined.

CHAPTER II.

SURVEYING FOR SMALL-SCALE OR GENERAL MAPS.

9. **Methods of Topographic Surveying.**—Three general methods of making topographic surveys have usually been employed in the past:

First, traversing or running out of contours by means of transit, chain or stadia, and level;

Second, cross-sectioning the area under survey with the same instruments; and

Third, triangulation of the territory under survey with such minuteness as to get a sufficient number of vertical and horizontal locations to permit of connecting these in office by contour lines.

All three methods are slow and expensive, while the first two are unfitted to the survey of large areas, because of the inaccuracies introduced in linear or traverse surveys.

A *fourth method, and that which this book is designed to expound*, is that always employed by the United States Geological Survey as well as to a lesser degree by several other American and European surveys. It is fitted to make topographic maps for any purpose, on any scales, and of any area. This consists of a combination of trigonometric, traverse, and hypsometric surveying to supply the controlling skeleton, supplemented by the "sketching in" of contour lines and details by a trained topographer. In this method the contour lines are never actually run out nor is the country actually cross-sectioned. Only sufficient trigonometric control is obtained to tie the whole together, the minor control

between this being filled in: first, in the most favorable triangulation country almost wholly by trigonometric methods; second, in less favorable triangulation country by traverses connecting the trigonometric points.

There are two general methods of making a contour topographic map which have been aptly styled the "regular" and the "irregular." These might be respectively called the old and the new. The old or *regular method* includes the surveying and leveling of a skeleton work of controlling traverse or triangulation and the cross-sectioning of the terrane into rectangular areas, the outlines of which are traversed and leveled. In addition the leveled profiles and traverses are continued between this gridironing at places where important changes of slope occur, and finally the survey and leveling of flying lines or partial sections is extended from each station. By this method the base of each level section or the contour line or line of equal elevation is determined by setting the instrument in position where this level line intersects the profile, and using the telescope as a leveling instrument with its cross-hairs fixed on a staff at the height of the optical axis, a line is then located by tracing successive positions of a stadia rod or by locating by intersection successive points on the level line, and a line drawn through these points locates the contour curve. In addition, parts of several level sections are plotted from one station by intersection on, or location of a staff, and by the determination of its height above or below the instrument by vertical angulation. In this mode of topographic surveying pegs are usually driven at regular intervals and their heights determined by spirit-level and vertical angulation.

The new or *irregular method* of topographic surveying consists in determining by trigonometric methods the position and height of a number of critical points of the terrane and connecting these by traverses and levels, not run on a cross-section or rectangular system, but irregularly, so as to give

plans and profiles of the higher and lower levels of the country, as ridge summits or divides and valley bottoms or drainage lines, such lines being run over the most easily traversed routes, as trails or roads. With the numerous positions and heights determined by the triangulation, and on these traverses as controlling elements, contour lines are sketched in by eye and by the aid of the hand-level on a plane-table with the country in constant view. This is the method now generally employed by expert topographers, and the work is so conducted that the development of the map proceeds with the survey of the skeleton and rarely necessitates the return to a station when once occupied. Moreover, it calls for the location of less points and the running of fewer traverses and profiles, and these over more easily traveled routes, than the former method. It is therefore more expeditious, cheaper, and the resulting map is a better representation of the surface, as it possesses not only the mathematical elements of instrumental location, which in the old method are arbitrarily connected in office, but also the artistic element produced by connecting the lines of equal elevation in the field, with the country at all times immediately before the eye.

10. Geological Survey Method of Topographic Surveying.—In average country, favorable for triangulation, comparatively clear of timber and well opened with roads, a skeleton trigonometric survey (Chap. IX) is made, by which the positions and elevations of all summits are obtained, as well as the horizontal positions of a few points in villages or at road crossings, junctions, etc. This constitutes the upper system of *control* (Fig. 1). Below and between this is a network of road traverses (Chap. X) supplemented by vertical-angulation (Chap. XVII) or spirit levels (Chap. XV) for elevations, and these follow the most easy routes of travel, not cross-sectioning the country in the true sense, but following all the lower lines or stream bottoms, as well as the gradients pursued by roads (Fig. 2). Between these two

upper and lower sets of control points there are therefore many intermediate ones obtained by road traverses, and the topographer, by observation from the various positions which he assumes and with the knowledge he possesses of topographic forms, sketches the direction of the contour lines. These are tied accurately to their positions by the large amount of mathematical control already obtained, supplemented by additional traverses or vertical angles where such are found wanting. (Art. 162.)

The *instruments* used are as various as are the methods of survey employed; the essential instruments being the plane-table and the telescopic alidade (Chap. VII), which invariably replace the transit (Art. 85) or compass (Art. 91), so that all surveying is accompanied by mapping at the same time, and there is no tedious and confusing plotting from field-notes to be done later in office. Nor are any of the salient features of the topography of the region lost through neglect to run traverses or obtain positions or elevations, all omissions of this kind being evident from an inspection of the map while in process of construction. The distances are obtained by triangulation with the plane-table (Art. 73) and by odometer measurements (Art. 98), supplemented off the roads by stadia measures (Chap. XII) or in very heavily wooded country by chaining (Art. 99) and pacing (Art. 95).

The *underlying principles* of this method of topography are, first, a knowledge of and experience in various methods of surveying, and a topographic instinct or ability to appreciate topographic forms, which is acquired only after long practice; and, second, a constant realization of the relation of scale to the amount of control required and methods of survey pursued; no more instrumental work being done than is actually required to properly control the sketching, and no more accurate method being employed than is necessary to plotting within reasonable limits of error. Thus, where trigonometric locations (Chap. IX) are sufficiently close together, crude

odometer traverses (Art. 98) or even paced traverses (Art. 95) can be run with sufficient accuracy to tie between these with inappreciable errors. Where trigonometric locations are more distantly situated, the spaces between them must be cut up by more accurate traverses, as those with stadia (Chap. XII) or chain (Art. 99), these again being gridironed by less accurate odometer or paced traverses. Again, a primary system of spirit-leveling (Chap. XV) or accurate vertical triangulation (Chap. XVII) is employed only for the larger skeleton, these elevations being connected by less accurate vertical-angle lines or flying spirit-levels, and these again by aneroid (Art. 176), each method being employed in turn so that the least elements of control obtained may still be plotted well within a reasonable limit of error in horizontal location of contour line.

Finally, *speed and economy* are obtained by traveling the roads and trails in wheeled vehicles or on horseback, at a rapid gait from instrument station to instrument station; the slower process of walking being only resorted to where roads and trails are insufficient in number to give adequate control and view of every feature mapped.

11. Organization of Field Survey.—The party organization and the method of distributing the various functions of topographic surveying among the members of the party must necessarily differ with the scale of the map and the character of the region under survey. The work involved in making a topographic or geographic map may comprise four operations:

First. The location of the map upon the surface of the earth by means of astronomic observations.

Second. The horizontal location of points, which is usually of three grades of accuracy: primary triangulation or traverse; secondary triangulation or traverse; and tertiary traverse and meander for the location of details.

Third. The measurement of heights, which usually accompanies the horizontal location and may be similarly di-

vided into three classes, dependent upon their degree of accuracy.

Fourth. The sketching of the map.

If the area under examination is small or the scale be of topographic magnitude, the first of the foregoing operations may be omitted, when the topographic party will have (1) To determine the horizontal positions of points; (2) To measure the heights of these points; and (3) To sketch in the map details as controlled by the horizontal and vertical locations so procured.

Where map-making is executed for geographic or exploratory purposes and on a small scale in open triangulation country, as that in the arid regions of the West, the skilled force may consist of only the topographer in charge. Where the map scale is increased up to topographic dimensions or the country is hidden from view by timber or because of its lack of relief, the topographer may be assisted by one or more aides whose functions will be variously performed according to the conditions of the country.

12. Surveying Open Country.—In making a geographic map on scales varying, say, from one-half mile to four miles to the inch in open, rolling, or mountainous country suited to triangulation, all sketching and the execution of the plane-table triangulation (Chap. IX) or other control should be done by the topographer in charge. He may be aided by one to three assistants according to the speed with which he is able to work and the difficulties encountered by the assistants in leveling (Chap. XV). It is assumed that the topographer has a fixed area to map, and that within this area he is in possession of the geodetic positions (Chap. XXIX) of two or more prominent points and the altitude of at least one.

With the positions of these points platted on his plane-table sheet (Art. 188) he proceeds, as outlined in Article 54, to make a reconnaissance of the area for the erection of signals and to locate prominent points on summits and in the

lower or drainage lines of the country by plane-table triangulation (Art. 73). Meantime, one assistant may be running lines of spirit-levels (Chap. XV) for the control of the vertical element, while one or two assistants are making odometer (Art. 98) or stadia traverses (Chap. XII) of roads or trails for the control of the sketching and the mapping in plan of the roads and streams. This preliminary control executed, the topographer adjusts to his triangulation locations the traverses run by the assistants (Art. 81), and writes upon them in their proper places the elevations determined by leveling or or vertical angulation (Chap. XVII).

In Fig. 1 is shown a typical *triangulation control sheet*, the directions of the sight lines being indicated so as to show the mode of derivation of the various locations. The stations and located intersection points are numbered in order to show the sequence in which they were procured. The *traversing* executed for the same region is illustrated in Fig. 2, from which it will be seen that merely the plans of the roads with their various bends, stream crossings, and the houses along them were mapped. Hill summits and other prominent objects to one side or other of the traversed route were intersected (Art. 84) in order to give additional locations and to facilitate the adjustment of the traverse to the triangulation. The closure errors of the various traversed circuits are shown, and an inspection of these makes it clear that in every case the errors in traverse work are so small as not to affect the quality of the control, because the adjustment of the traverses by means of points on them which are located by the plane-table triangulation will distribute the errors in the various road tangents in such manner as to make them imperceptibly small on the resulting map. The product of such adjustment is shown on Fig. 3, which is the base on which the topographer begins his sketching. On this *sketch sheet* are the locations obtained by him in the execution of his plane-table triangulation, the traverses as adjusted to this control, and

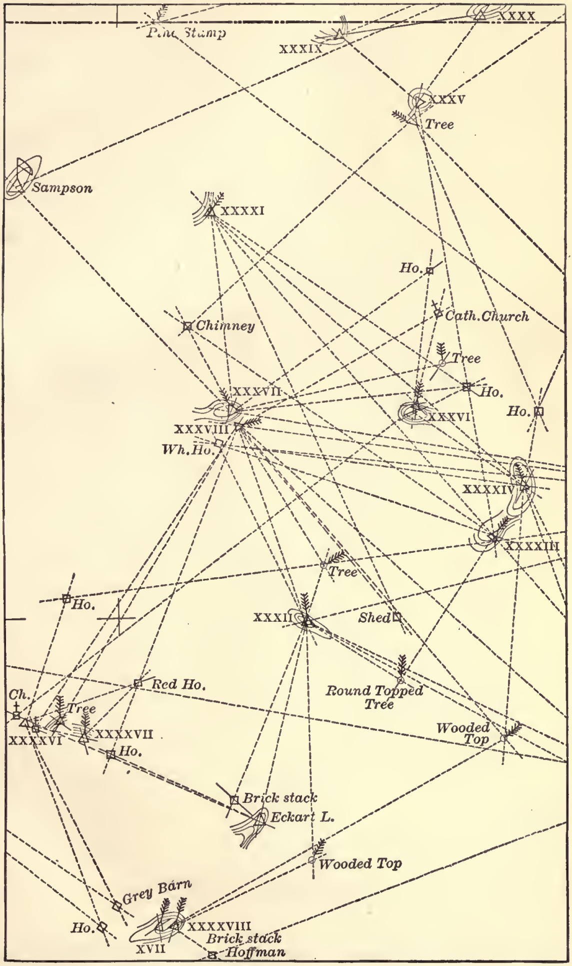


FIG. 1. — DIAGRAM OF PLANE-TABLE TRIANGULATION. FROSTBURG, MD.
Scale $\frac{1}{62500}$.

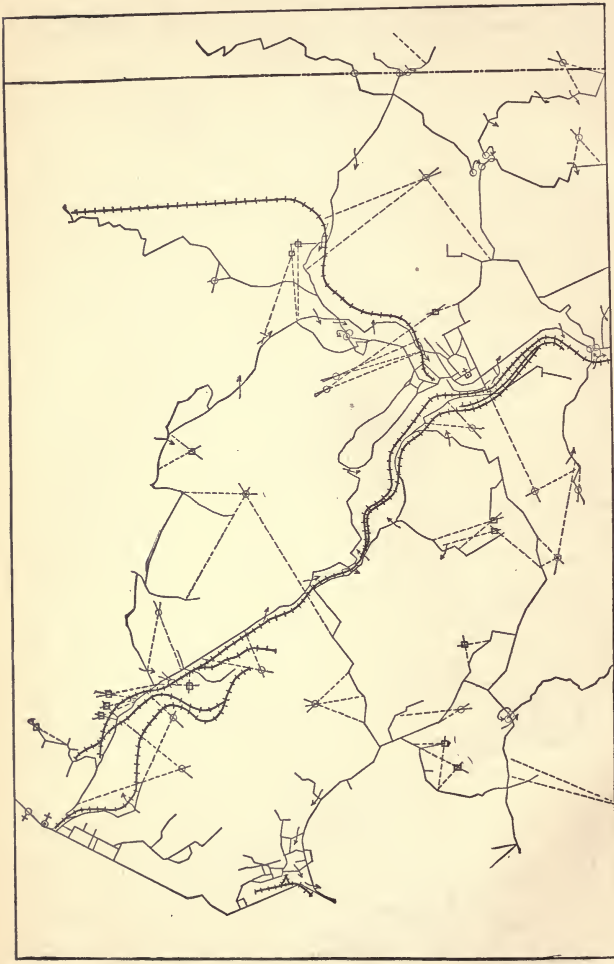


FIG. 2.—ROADS, HOUSES, AND LOCATIONS RESULTING FROM TRAVERSE.
FROSTBURG, MD.
Scale $\frac{1}{62500}$.

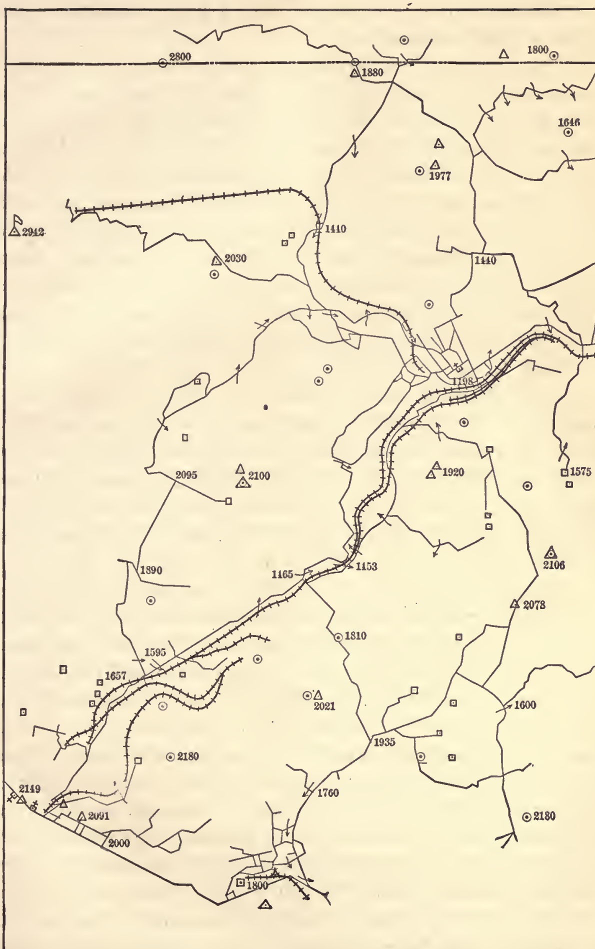


FIG. 3.—ADJUSTED SKETCH SHEET. FROSTBURG, MD.
Scale $\frac{1}{62500}$.

elevations from vertical angulation or spirit-leveling written in their appropriate places.

If the work be the making of a topographic map on scales larger than those above described, and the country be still of the same topographic character—namely, open, with salient summits,—a system of control similar to the above must in like manner first be executed by the development of plane-table triangulation and the running of control, traverse, and level lines. But the after-work of sketching the map will be conducted in a different manner than for the smaller scales, because of the greater detail required, the shorter distances to be traveled by the topographer in performing the work, and his consequent nearness to the various features which he is to map.

13. **Sketching Open Country.** — Having the control platted on the sketch sheet as shown in Fig. 3, and where roads are sufficiently abundant to cut up the map with traverses so near one to the other that the topographer may not have to sketch more than one-half to one inch to either side of his position, the sketching of the topography proceeds as follows:

Taking the sketch sheet on a board in his lap, the topographer for cheapness and convenience, because of the speed, drives over every road. Where these are not sufficiently near one to the other he walks in between them, pacing distance (Art. 95), and getting direction by sighting fixed objects, while he sketches the plan of the contour lines (Art. 193) as far as he can safely see them to either side of his path. This operation is performed by setting out from such fixed points as a road junction, a located house, or a stream crossing, the position of which is platted on his map and the elevation of which is known. Adjusting the index of his aneroid at the known elevation (Art. 176), he drives along, keeping the platted direction of the road parallel to its position on the ground and marking on the map the positions at which the

various contours are crossed by his route. Thus, if his contour interval be twenty feet, at every change of twenty feet as indicated by the barometer he stops, and, knowing his position on the map either by reference to bends in the roads, houses, or by having counted the revolutions of his wheel from a known point, he glances along the trend of the slopes to one side or the other, following by eye the level line of his contour, and this he sketches in horizontal plan upon the map. At first he may be aided in this by a hand-level (Art. 156), but as he acquires skill with practice he is able to estimate the position and direction of the contour line to either side with great accuracy, and finally to interpolate other contours above and below that on which he is placed with such precision as not to affect the quality of the resulting map by a contour interval.

The aneroid being an unreliable instrument, he must not drive more than two or three miles without checking it at a well-determined elevation. This he is usually able to do at houses, or hill-summits, or other points the positions of which have been determined by his prior control. If he is not able so to check his aneroid, he hastily sets up his plane-table, reads with the telescopic alidade a few vertical angles (Art. 162) to hilltops or houses in sight and the elevations of which are known, and, with these angles and the distances which he can measure from his position to the points sighted as shown on the adjusted control, he is at once able to compute the elevation of his position (Art. 161) within two or three feet and thus check his aneroid. At the same time he is in similar manner able frequently to throw out other elevations by sighting from the position thus determined to houses or summits near by which may have been located by the traverse (Art. 84), and the heights of which he determines now from his angulation. The topographer thus sketches the whole area assigned him, not only mapping the contours, drainage, political boundaries, and other topographic features, but also

checking the positions of houses and summits and the directions and bends of roads and streams as located by the traverseman (Fig. 4).

Where the hills are more prominent and the slopes bolder and steeper, the topographer sketches these from his various view points by *interpolating contours* between the located control points. With the sketch-board in his lap or on the tripod and approximately oriented, looking about in various directions at hill-summits, houses on slopes, spurs, etc., which may with their elevations be platted on his map, he first sketches in plan the streams and drainage lines as well as the directions of slopes. Then he sketches the position of contour lines about such control points as summits, salients, and his own position. With these as guides he is then unable to go astray in the interpolation of the intermediate contours which complete the map of the area immediately about him.

The sketching of the topography for *large-scale maps* differs rather in degree than in kind from the above. The large-scale map covering as it does a relatively small area, the topographer is not under the necessity of traveling with such speed as to necessitate his using wheeled conveyance. At the same time the largeness of the scale places the roads at much greater distances apart on the map and necessitates his traveling between these to greater extent. It will thus be seen that the scale and the ability to travel over the country work harmoniously one with the other. For the smaller geographic scales the roads are so close together on the map as to afford sufficient control and sufficient number of viewing points for sketching the topography of the average open country, whereas on large-scale topographic maps these roads are in plan much farther apart, but the time consumed in walking between them is a comparatively small item because of the decrease in the distances to be covered.

In sketching a large-scale map the topographer will have about the same relative amount of primary control as above

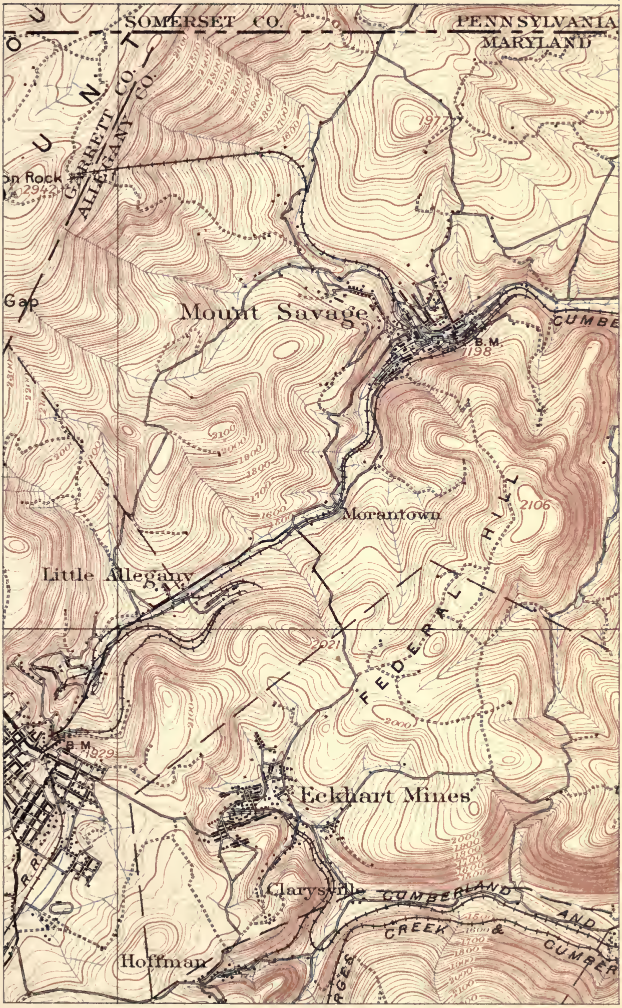


FIG. 4.—COMPLETED TOPOGRAPHIC MAP, FROSTBURG, MD.
Scale 1 to 62,500. Contour interval 20 ft.

indicated. Starting out with some known point and on foot, accompanied by one or more stadiamen, he sets up and orients his plane-table, and, having considerable areas to fill in on his map between his present position and his next recognizable natural feature, he posts the stadiamen at convenient changes in the slope of the country or at houses or trees or bends in the streams, and drawing direction lines and reading distances by stadia to these positions he obtains additional locations to control the sketching (Art. 101), which is executed as above described. In the progress of this work he not only determines horizontal positions by sighting to the rods held by his stadiamen, but also the vertical positions of the same points (Art. 102). For very large-scale maps and under some conditions the work may be expedited by permitting the assistants to sketch the contours immediately adjacent to their stadia stations, and these sketch notes must be given the topographer at frequent intervals to be transferred to his map. In this manner one topographer may handle from one to three stadiamen, providing he uses judgment in the selection of his and their positions. For smaller-scale topographic mapping the work may be expedited by the stadiamen riding on horseback from one position to another, or even by the topographer himself using this means to get about.

14. Surveying Woodland or Plains.—The securing of control in densely wooded country, as that of the Adirondack region or the woods of Minnesota, Michigan, and of Washington; or the securing of control for very flat plains country, as that of the Dakotas and Nebraska, is accomplished by different means than must be adopted in open triangulation country. Be the scale of the resulting map large or small, the primary control may be obtained most economically either by triangulation or by traverse methods. If the country is *wooded and rolling*, it may be more economical to clear the higher summits or to erect high viewing scaffolds upon them,

from which to conduct a skeleton plane-table triangulation. Intermediate positions may be obtained by placing signal-flags in tall trees and locating these by intersection or using them to obtain other positions by resection. With practice the topographer will thus triangulate the most forbidding woods country more expeditiously than it could otherwise be controlled, by taking advantage of every outlook, as a rock on a hillside, a lake, a small clearing for a farm, or by clearing or signaling the commanding summits. He will thus occupy only such points as those just described, locating by intersection (Art. 73) from them the flags on the more wooded and forbidding ones which may be the more commanding positions, and using the latter again for carrying on his work by resection (Art. 74).

In *level plains* or in wooded plateau land the control may of necessity be executed only by traverse methods. In such case where the scale is of geographic dimensions one or two astronomic stations should be determined (Part VI), or for larger scales it may suffice to assume the initial position. From this primary traverse lines should be run (Art. 226) at considerable distance one from the other, depending upon the scale. For the one-mile scale a nearness of fifteen to twenty miles will suffice. For the two-mile scale these primary traverse lines may be double the distance apart; for a large topographic scale a relatively smaller distance, depending upon the map scale; for all scales a distance corresponding to fifteen to twenty-five inches on the map according to the topography.

Between these primary traverse lines others of less accuracy should be run as a secondary control. On these distances should be measured by wheel (Art. 98) when the vehicle can be driven in straight tangents, by stadia (Art. 101) in open irregular country, or by chain (Art. 99) or tape (Art. 97) through underbrush or dense wood. Elevations will be secured in the woods by vertical angulation to stadia (Art. 102) or by spirit-leveling (Chap. XV); in the open

or plains by vertical angulation to fixed objects, as the eaves or chimneys or window-sills of houses, the platforms of windmills, etc. (Art. 160), or to the stadia-rod, as well as by spirit-leveling. The secondary traverse is usually executed by the party chief while his assistants are engaged in tertiary traverse for the filling in of topographic details or the procuring of vertical control.

The primary and secondary control having been procured as above, this should be platted on sketch sheets of the customary large plane-table size for open country (Art. 68), and preferably in small detached pieces placed on small boards of about six inches square, where the latter have to be carried through woods and underbrush. These control sheets will be not dissimilar to those described in Article 13, excepting that they will lack the location of points procured by angulation and will consist almost wholly of platted traverse lines. In order that the topographer when sketching may identify these lines on the ground, trees must be frequently blazed in woods when the traverses are being run and station numbers or elevations be written on the blazings.

15. Sketching Woodland or Plains.—With the control platted on the sketch sheet as just described, the topographer in *plains* work starts out and drives over the country much as described in Article 13, traveling over all the traversed roads and checking his aneroid by setting in at known elevations or by angulation to and from buildings and similar objects. As the country is relatively flat, the contour lines are at considerable distances apart in plan, and consequently a very small difference in vertical elevation makes a considerable change in the horizontal location of a contour. Therefore the determination of the vertical element should be of greater relative accuracy, that the resulting map may be correct.

In the *woods* the sketching is executed in an entirely different manner. Little skill is required in the depiction of the topography, as it is impossible to see the country and

therefore to sketch it in the ordinary sense. The topographer is limited to sketching that which is directly under foot—in other words, to mere contour crossings—and in order that these may be connected the traverses must be much nearer together, and not only the topographer but his more skillful assistants are all engaged in sketching and traversing at the same time. Starting out with the primary and secondary control as obtained in the last article, the topographer travels over those traversed routes which have been blazed and sketches the contours upon these while his assistants run additional traverses over controlling routes, as along stream beds and ridge crests, and so close together as to completely command all the country under foot. These traverses will be of crude quality, directions being obtained by sight alidade (Art. 62) and traverse-table (Art. 61), and distances by pacing (Art. 95) or by dragging a light linen tape (Art. 97). Each day the topographer must adjust to his control sheet the traverses with accompanying sketching as executed by his assistants. With such a skeleton of topography on highest and lowest lines, i.e., contour crossings of streams and ridges, he can readily interpolate contours for most of the intermediate spaces and, following after his assistants, fill in those places which are not fully mapped.

In the execution of a survey under such conditions the topographer's work is largely supervisory and consists chiefly in the management of the work of his assistants, the adjustment of their sketching, and its inspection as he fills in the details omitted by them. There is little room for them to go astray, because they only sketch that which they walk over. The topographer should invariably reserve for himself the higher ridges, the ponds, and the more open places in order that quality and speed may be obtained by the utilization of his skill in that work which gives some opportunity for sketching at a distance from the traveled route.

16. Control from Public Land Lines.—In the western

United States where the public land surveys have been executed in recent years and with sufficient accuracy to furnish horizontal control, this may come almost wholly from the township and section plats filed in the United States Land Office. The topographer takes into the field paper on which sections and quarter sections are ruled and numbered. On these he writes at the proper section corners the elevations as determined from the primary spirit-levels (Chap. XV). He also indicates on the northern and western margins of each township the offsets and fractional sections as shown on the published land plats (Fig. 5). At some period during the progress of field-work the topographer adjusts the land-line work to positions determined either by primary triangulation (Chap. XXV) or traverse (Chap. XXIII), supplementing this by additional control where necessary.

17. **Sketching over Public Land Lines.**—With the control sheet prepared as described in the last article, the topographer proceeds to drive over the section lines on which roads have been opened. The control sheet is attached to a plane-table board. Starting from a known section corner, he drives in a straight line down one of the section lines to other section corners, determining his position by counting revolutions of the wheel (Art. 98) and sketching contour crossings as he progresses.

Starting out with a known elevation from spirit-levels (Chap. XV), he determines other elevations as he proceeds by setting up his plane-table at a section corner or opposite a house which he can locate by odometer distance, and reads vertical angles from the point of known elevation to houses, windmills, or other objects in sight (Art. 162), drawing direction lines to them as an aid in their identification (Art. 84). Driving on until he comes to one of these objects and being thus able to locate it on his plane-table, he measures the distance from it to the point from which the angle was taken and at once computes his elevation (Art. 161). Or, setting up his

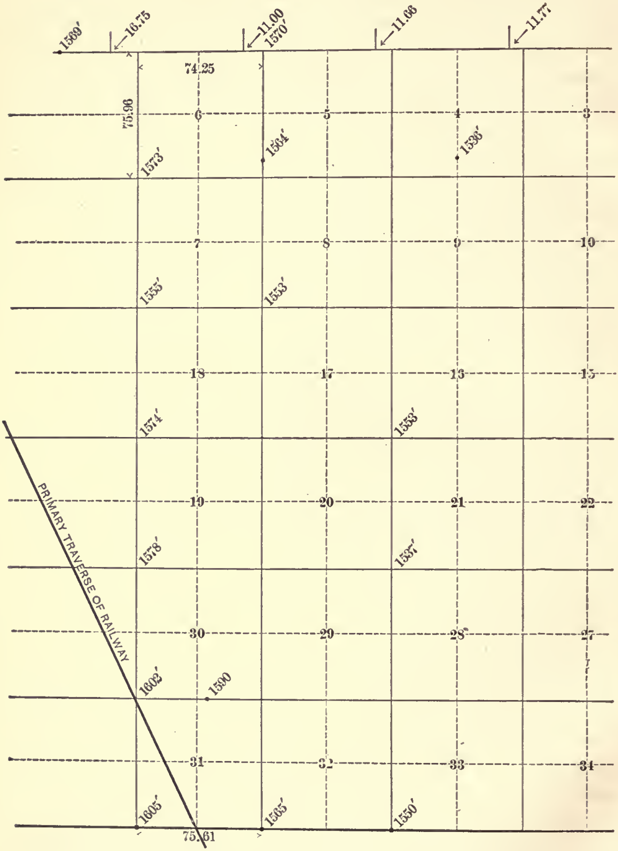


FIG. 5.—LAND SURVEY CONTROL FOR TOPOGRAPHIC SKETCHING. NORTH DAKOTA.
Original scale 2 inches to 1 mile.

plane-table board from some known position, as determined from his section lines and odometer, he reads vertical angles to houses or windmills, the heights of which have already been determined by vertical angulation, and thus brings down to his present position an elevation by means of the angle read and distance measured on his board. In conducting vertical angulation in this manner care must be taken to sight at some well-defined point, as a platform or top of a windmill, the gable or top of a house or top of door-sill, etc.

As the sketching is a comparatively simple process under these conditions because of the flatness of the terrane, his work may be expedited by permitting his more skillful *assistants to aid in sketching*. In order that he may control their work he drives and sketches over those roads which parallel the roads of his assistants on either side, and in such manner obtains a clear insight into the work performed by them. The assistants may determine elevations either by vertical angulation, as does the party chief, or by aneroid frequently checked, say at distances not exceeding two miles between the better elevations obtained by the topographer. On such a sketch sheet as it comes from the plane-table board (Fig. 6) the roads have been clearly marked over the section lines and additional diagonal roads have been traversed or sketched directly on the plane-table board, controlled by section corners, the outlines of lakes having been obtained by stadia (Art. 101).

Where the topographic map is made at the same time as the subdivision of the public lands, as was the case in the Indian Territory surveys of the United States Geological Survey, the cost of executing the topographic survey scarcely exceeds the cost necessarily involved in making the land subdivision or cadastral survey. The only additional cost in the execution of the topographic survey is that for leveling. Fig. 33 is an example of the cadastral map resulting from such a survey of the public lands. The topographic map of

the same region corresponds in appearance almost identically with that shown in Fig. 6, being shorn of the various symbols used on the Land Survey Maps.

18. Cost of Topographic Surveys.—As indicated in Tables I, II, and III, the cost of topographic surveying varies widely with the character of the country, the scale of the map, and the contour interval. Such topographic surveys as are executed by the United States Geological Survey range in cost for maps of a scale of one mile to the inch and 20-foot contour interval, similar to those described for *open country* in Articles 12 and 13, from $10.00 to $20.00 per square mile. Such as are described in Articles 14 and 15, for *plains or woodland*, range in price from $8.00 to $12.00 per square mile for the former to between $15.00 and $30.00 for the latter. The highest-priced work of this kind which can be executed being the woodland survey, and the cheapest country to map topographically being the open plain.

Land-survey country, as that instanced in Article 16, which is a survey of a portion of North Dakota, ranges in cost from $5.00 to $8.00 per square mile, where the topographic map is made on a scale of two miles to one inch and in 20-foot contours. For the same scale and in mountainous country, as that of the South and West, the cost is from $8.00 to $12.00 per square mile.

If any endeavor is made to do work for other purposes than the procurement of a topographic map, as for the determination of land lines or the staking out of canals or railroads, the cost of the survey is at once greatly enhanced. It is this which has added so greatly to the relative cost as shown in the tables cited of some private topographic surveys as well as of the cadastral surveys.

19. Art of Topographic Sketching.—Mr. A. M. Wellington aptly said of topographic surveying that "the sketching of the form of the terrane by eye is truly an art as distinguished from a science, which latter, however difficult it

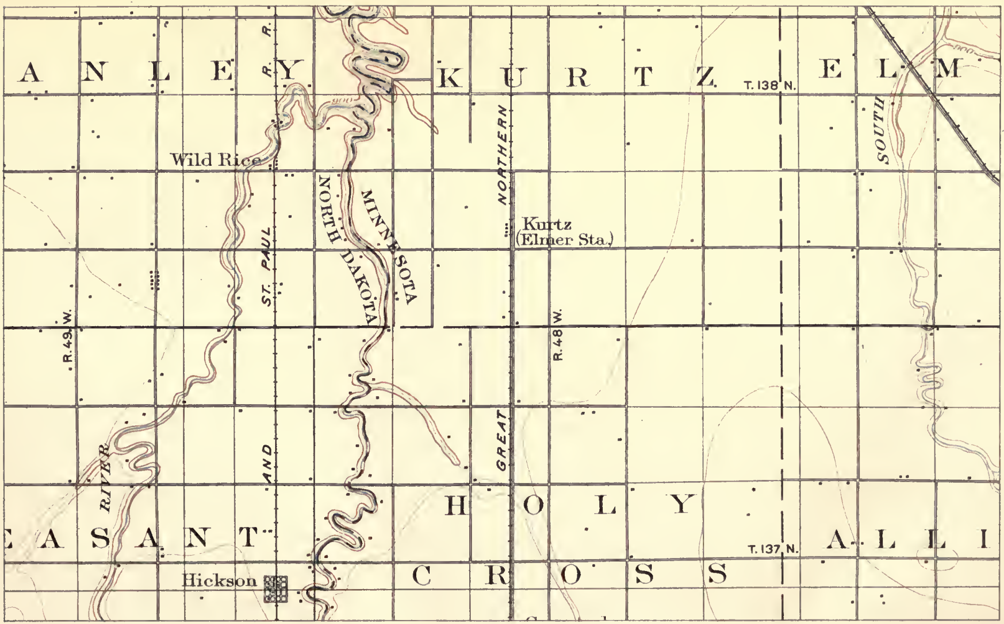


FIG. 6.—TOPOGRAPHIC MAP ON LAND SURVEY CONTROL, NEAR FARGO, N. D.
Scale 1 to 125,000. Contour interval 20 ft.

may be, is always susceptible to rigorous and exact analysis. An art, on the other hand, is something which cannot be taught by definite, fixed rules which must be exactly followed, though instruction may be given in its general principles."

In representing the heights and slopes of a given piece of country by contour lines, every case presents some peculiarities which must be met, as they are presented, by the topographer's own resources. No hard-and-fast limit of minuteness of detail can be previously fixed. The scale chosen for the topographic map limits this to a certain extent, but its exact limits must be set by the topographer's own experience and good judgment, that he may *discriminate between important and trifling features;* those which are usual and common to the region being mapped, and those which are accidental or uncommon, and which should therefore be accentuated. Above all, the topographer must exhibit an alertness to distinguish as to what amount of detail should be omitted and that which should be included. Hesitancy in this is the chief source of slow progress. Valuable time may be wasted in the representation of features which may be lost on the scale of the work and which are common in all localities to the topographic forms being sketched; while features characteristic of such special topographic forms as those produced by eruption, erosion, or abrasion, or those indicative of the structure of the region and which give distinctive character to its topography, may be lost sight of or be covered up in the map by too careful attention to minute details.

The *characteristic features* of a terrane are best observed from a point nearly on the same level; and as between sketching features from above or below for a reasonable range, sketching from below is the better, as features viewed from any considerable height above are apt to appear dwarfed and much detail of undulation of the surface lost sight of. Yet, as a precise representation of the land requires sketch-

ing its forms from numerous positions at intervals not far apart, the necessity will rarely arise of observing surface forms from points of observation much above or below the surface represented, excepting in case of very small scale geographic or exploratory surveys.

20. Optical Illusions in Sketching Topography.—In sketching topographic forms by eye there are a number of optical illusions to which it is well to call attention, though the effect of these can be entirely overlooked in the sketching of detailed topography such as would be mapped on scales less than one mile to the inch. But for the sketching of topographic maps on smaller scales, where the eye has to be more depended upon, these illusions become more important. Most of these have been well classified by Mr. A. M. Wellington in his admirable work on railway location, and they are here summarized, with variations, from that work. Among the more serious of such illusions are the following:

1. The *eye foreshortens* the distance in an air line and materially exaggerates the comparative length of a lateral offset so as to greatly exaggerate the loss of distance from any deflection.

2. The *eye* exaggerates the sharpness of projecting points and spurs, and accordingly *exaggerates the angles.*

3. In looking, however, at smooth or gentle slopes from a distance, the tendency of the eye is to decrease the angle so that in such country as the rolling plains of the West *slopes look much gentler*, the inclinations much less, than they are in fact.

4. In this connection the eye is liable to make *slopes* looked at from a distance *appear steeper and higher* than they are in fact, when they are compared with known slopes and elevations of lesser dimensions near by.

5. Again, the unaccustomed eye, which mentally measures all dimensions by referring them to those with which it is acquainted, is apt to make a *divide or pass appear lower*

than a nearer divide or pass to which it is referred in one sweep of the vision, whereas it may be higher (Fig. 7).

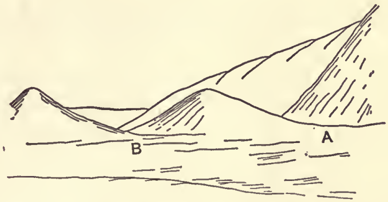


FIG. 7.—OPTICAL ILLUSION AS TO RELATIVE HEIGHTS OF DIVIDES. *A* is nearer and lower than *B*.

6. The *eye* invariably *exaggerates the steepness of the slopes* of mountains, these appearing to have inclinations of from 60 degrees to almost vertical, whereas in fact the steepest slopes are rarely as great as 45 degrees.

7. The eye trained to estimate slopes and distances in regions of large topographic features—that is, regions of extreme relief or differences of elevation—will be at a disadvantage in making similar estimates in a country in which the differences of elevation are small. The tendency of one accustomed to estimating the topographic forms in the Rocky Mountains, where differences of elevation and distances visible to one sweep of the eye are great, will be to overestimate heights and distances in the less rugged country of the Eastern States, where great detail in topography exists, and thus deceives the eye into an *exaggerated notion of the amount of the relief*.

8. In viewing the terrane with an idea of estimating its roughness as affording a possible route for railways, canals, or similar works, a rugged mountain gorge with occasional precipitous narrows, separated by river flats, may appear much more difficult and much rougher than it is in fact. This is especially so as compared with a gently undulating or rolling

country, which, when viewed from a distance, appears to be comparatively level, while a nearer view will show it to be full of elevations or depressions which will render construction most expensive, because of the rapid and numerous succession of large cuts and fills.

The effect on the eye and the mind is to *exaggerate the ruggedness of a country* which is difficult to travel because of such impediments as broken stone, fallen timber, creeks, and swamps, whereas a region where travel is easy and free, as in open rolling plains country or where good roads abound, is often estimated to be much simpler and more level topographically than is the other region.

CHAPTER III.

SURVEYING FOR DETAILED OR SPECIAL MAPS.

21. Topography for Railway Location.—Some of the worst errors in engineering location originate in reconnaissance, for the reason that the average reconnaissance surveys are not of areas, but of routes or lines, and there is great danger of serious error in the selection of the line to be surveyed. It may, accordingly, be stated that a *railway reconnaissance* should not be of a line, but of an area sufficiently wide on each side of an air line between the fixed termini to include the most circuitous routes connecting these. The results of such a survey should be embodied in a topographic map of greater or less detail, according to the nature and extent of the country. If the reconnaissance be of a great railroad, such as some of the Pacific roads, built through hundreds of miles of unknown country the resulting map should be on a small scale, perhaps 2 to 4 miles to the inch, and with contour intervals varying from 20 to 100 or 200 feet, according to the differences of elevation encountered and the probable positions of several locations. With such maps as those of the U. S. Geological Survey, the number of possible routes may be reduced to two or three, and a more detailed topographic survey should then be made of these on which to plan the final location.

As ordinarily practiced, topographic surveys for railways are made by the older methods, with transit and chain or stadia and with spirit-level; notes of the surveys are kept with accompanying sketches in note-books, and these are reduced to map form in the office. The same results can be much

more satisfactorily and more rapidly procured by using the plane-table in place of the transit, and the resulting map, being plotted in the field, is a more accurate and available representation of the terrane than can possibly be made from plotting notes in an office.

The *Germans*, who are very thorough in *taking topography for railroads*, divide the work into three separate surveys of different degrees of accuracy: first, recourse is had to the government topographic maps on a scale of approximately 1:100,000, and on this a preliminary route or routes are laid down: second, a more detailed topographic survey is made in the field on a scale of 1:2500 as a maximum or 1:10,000 as a minimum, with contour lines of 15 feet interval. This map is limited in area from a few yards to a few hundred yards in width, according to the nature of the country. Where no previous small-scale topographic survey exists, the base of this more detailed or second survey is a transit (Art. 87) or plane-table (Art. 83) and level (Art. 129) traverse, following as nearly as possible the approximate route of the proposed railway. Bench-marks (Art. 135) are established along this at distances of from 500 to 1000 feet, by which the aneroid may be checked. With this transit line completed on the proper scale, the topographer goes over the ground and, by means of distances from pacing (Art. 95) or odometer (Art. 98), and elevations by aneroid (Art. 176), constructs a hasty contour map on which are indicated all roads, watercourses, structures, high-water marks of bridges, width and height of existing bridges and culverts; and all other necessary topographic details as to the position of rock masses, strike and dip of strata, swamps, springs, quarries, etc.

On such a map as this, hastily and cheaply made, it is possible to plan the detailed topographic map, limited from a few yards to 100 or 200 yards in width and covering what will practically be the final route of the located line as obtained from the second survey. This *final detailed survey*,

from which the paper location is to be taken, should be on a scale of from 1:500 up to 1:1000 and with contours of about 5 feet interval, more or less, according to the nature of the land. There is plotted on the plane-table sheet the transit and level base line previously run for the second survey, and the instruments now used by the topographer are of a more accurate nature, consisting of a plane-table (Arts. 58 and 83) for direction and mapping, two or more stadia rodmen for distances (Art. 102), while elevations are had by vertical angles with the alidade (Art. 59). On this final map are shown much the same topographic details as on the second, but all are more accurately located and the elevations are of a more refined nature. The data furnished by this final map will serve all the purposes of making a last *paper location* of the line, from which the engineer will in the field possibly deviate according to the appearance of the route traveled as presented to his eye when the location is laid down.

Mr. Wellington's location of the Jalapa branch of the Mexican Central Railway (Fig. 8) is an excellent example of a detailed contour topographic map for railway location. This was platted in the field on the scale of 1:1000, or about $83\frac{1}{3}$ feet to 1 inch. The contour interval was 2 meters, or 6.56 feet.

22. Detailed Topographic Surveys for Railway Location.—Prior to making the location, which may be made in part from the notes of preliminary surveys, a narrow belt of topography should be mapped in detail, its width being restricted as far as possible, providing the preliminaries have been skillfully conducted or have been preceded by a small-scale topographic map executed with especial care along the possible routes of the location (Art. 21). On the detailed topographic map a *paper location* may be made, from which full notes of the alignment can be derived, the points of curve and tangent taken off, and a profile of the paper location pre-

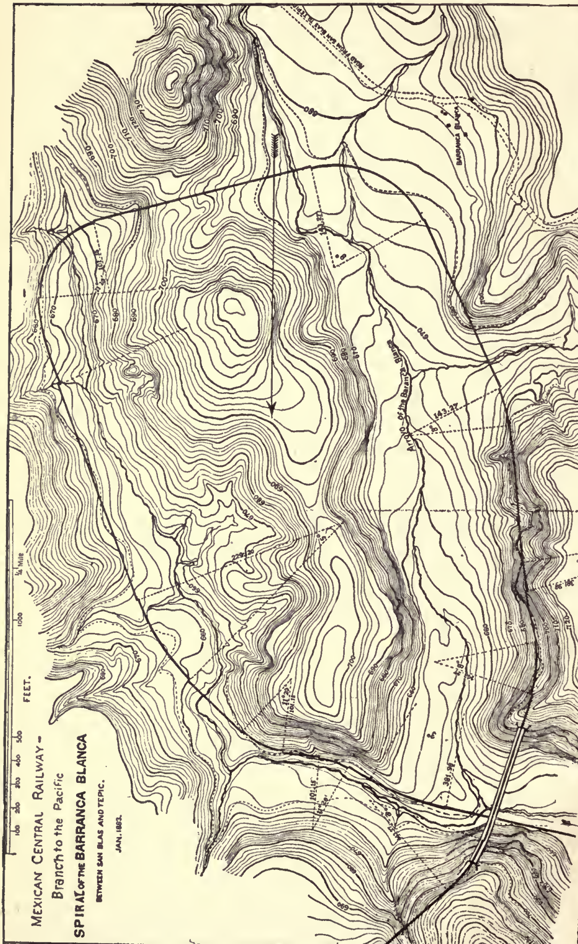


FIG. 8.—CONTOUR TOPOGRAPHIC SURVEY FOR LOCATION OF MEXICAN CENTRAL RAILWAY.
Scale of original 83⅓ ft. to 1 inch. Contour interval 6.5 ft.

pared. For the making of the paper location the topography should be as exact and the contour lines should be as accurately placed as the scale of the map will permit, in order that a line may be located upon the map and a profile called off from it which shall agree as closely as possible with the subsequent transit location and spirit-level profile. In running the field location from a paper location, the projected profile and not the projected alignment must be run.

In making such a map it is neither necessary nor possible to locate every point on each contour, the horizontal and vertical locations of the contours being at such distances apart that their projections on the map will be so close together that in connecting them by eye in the field the topographer cannot go astray by an appreciable distance. With a detailed contour map made as described for the location of canals (Art. 23), a *grade contour* or location line may be drawn which will show where the plane of the roadbed will cut the natural surface and from which it will at once be seen whether or not the location is the most favorable the topography will permit.

The error into which many have fallen is in assuming too much or too little for the topography as a guide to location. The topographic map fails to show many essentials requisite in making a location, as it gives no evidence of the materials to be encountered, nor does it convey an adequate idea of the magnitude of the excavations and fills. The topographic map must be supplemented by a careful *visual reconnaissance* of the line which it covers. Such topography should therefore be restricted in its width and amount, and no attempt should be made to make a final location from such a map. On the other hand, where a topographic map is not made, and too much reliance is placed on the visual reconnaissance of the country, the greatest errors are at once introduced in encountering a bad system of gradients, in overlooking important towns, or in otherwise selecting inappropriate routes.

In planning the location on a detailed topographic map, the engineer should begin at a summit or similar fixed point, assuming or taking from a guide-map an initial elevation. Then with a pair of dividers he should step off such distances that these will correspond to the grade chosen and their termini end on the map above or below such contours as will give the proper differences in elevation to produce such grades. By this means a *grade contour* can be sketched in on the map and then connected by tangent lines. The latter must, in turn, be connected by throwing in curves the radii of which shall be as large as possible, care being taken that the grades on these shall be properly compensated. With such a paper location it is then possible, by means of scale and protractor, to take off the directions and distances in a note-book, when, with these as a guide, the located line may be run on the ground and changed or modified in the field as the visual observation of the engineer may suggest.

Speed in mapping railway topography varies greatly with the scale selected and the character of the land mapped. One party working in flat, desert country in Utah ran 20 linear miles in a day of 9 hours, including running of spirit-levels. The same party working later in mountainous country in Washington averaged during a long period of time less than $\frac{1}{4}$ mile a day, in one instance working six weeks on a location through $1\frac{1}{2}$ miles of canyon. A party working on railway location and mapping topography on the plains of Kansas made an average speed of 2.1 miles a day at an average cost, including all expenses, of $11.03 per linear mile. The Utah work averaged about $2.50 per mile, and the cost of much of the Washington work exceeded $100.00 per linear mile.

23. Topographic Survey for Canal Location.—Surveys for canal lines or lines of conduits, etc., are best made by having the leveling (Chap. XV) precede the plane-table or transit work. The level will then run out a grade contour having the requisite fall per mile, and the transit (Art. 87) or plane-table

(Art. 83) with chain measurements (Art. 99) will follow the level, locating this grade contour. Topography may be taken on either side by stadia (Art. 101) and plane-table so that in the final location of the canal the preliminary grade contour may be shifted to suit the sketched topography, much as the line of a railway location would be shifted from similar data (Art. 22).

An interesting example of a detailed topographic survey for the final *location of* an *irrigation canal* is that made by Mr. J. B. Lippincott of the Santa Ana Canal, through a rocky canyon. This location was made upon a carefully prepared topographic map drawn on a scale of 50 feet to 1 inch, with contour interval of 5 feet. The maps were plotted from cross-section notes based on two connected and approximately parallel preliminary lines, the contour curves being sketched in the field to indicate intervening irregularities of surface. The preliminary controlling lines were carefully run with transit and chain, were frequently connected, and had a vertical interval of 70 feet. The space between and for thirty feet above the upper line, or for a total of 100 feet vertically, was carefully contoured. From the map thus prepared a more accurate cross-sectioning was made, and from these notes a new contour map of the ground was prepared on a scale of 30 feet to an inch over the more difficult portions of the line, after a preliminary location had been selected on the first contour map. Fig. 9 gives a plat of one of the roughest portions of this line, and on it are shown in small circles the various points located on each contour. The plane-table was used and was set up generally as shown by the station numbers and triangles on the preliminary and plotted traverses, and directions were measured to stadia-rods held at various points on the 10-foot contour lines (Art. 101). The positions of the contour lines at these points were therefore plotted, and the corresponding elevations were immediately connected as contour lines on the plane-table sheet. In this

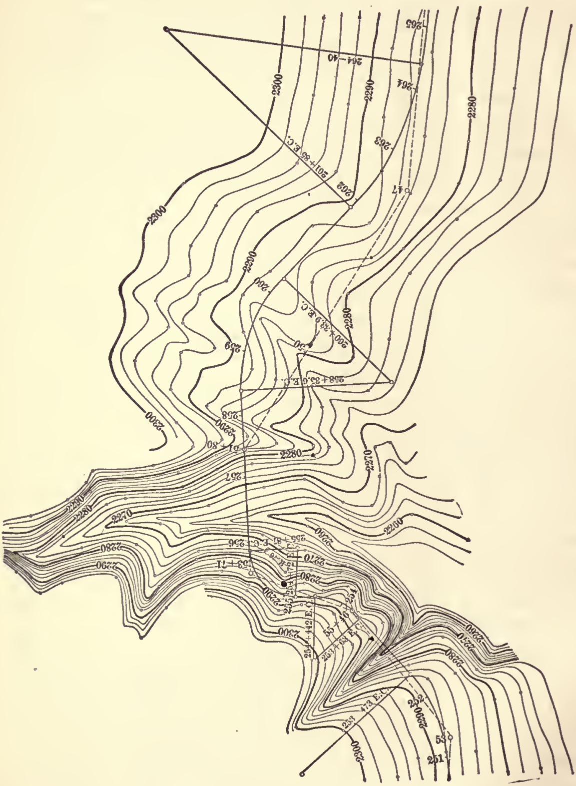


FIG. 9.—DETAILED CONTOUR SURVEY FOR CANAL LOCATION.
Original scale 100 ft. to 1 inch. Contour interval 2 ft.

way enough points were located on each contour to sufficiently control it, and the immediate 2-foot contour lines were interpolated by eye estimation in the field.

In doing this work *three* various *methods* were *tried:* (1), by locating the contour lines with slope-board and rod; (2), by locating the contours at right angles to the stations occupied by a levelman using a hand-level (Art. 156); and (3), by means of the plane-table and stadia (Art. 101). Mr. Lippincott says that as a result of these tests there is no question between the quality of the three classes of work; that without plane-table the work had to be plotted up in office and located points connected by estimation or from rough sketches; with the plane-table the same points were plotted immediately, in the field, and the connections between these made with the terrane in view, and that the resulting map by plane-table much more accurately expressed the slopes of the land than did the maps made by the other methods. The *speed* by the various methods was about the same. The party consisted generally of five persons, including the topographer, levelman, and rodman, and the speed was from 2500 to 4000 linear feet per day, actually locating four 10-foot contours and sketching in five or six more, a total of 100 feet vertical interval, and interpolating the 2-foot contours. Where side canyons and ravines were passed the slope-board was found to be entirely inadequate and helpless, while by the use of levelman and hand-level without the plane-table, and with taped traverse lines, the conditions were improved, but the work was of the crudest character so far as its topographic expression was concerned.

An example of a *preliminary topographic survey of a canal line*, made under the author with plane-table and on a small scale to determine the possibility of bringing the water from a stream or reservoir to certain lands for purposes of irrigation, is illustrated in Fig. 10. The scale of this illustration is denoted by the land section lines, each section

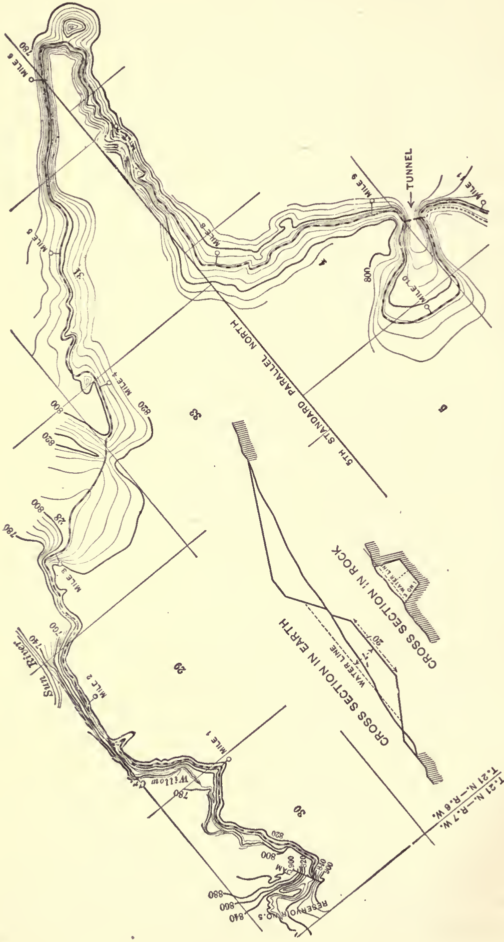


Fig. 10.—Preliminary Map of Canal. Montana.
Scale 4000 ft. to 1 inch. Contour interval 4 ft.

being a mile on a side. The original survey was made on a scale of 3000 feet to the inch, with a contour interval of 4 feet. The plane-table was accompanied by a spirit-level to determine grade, in order that the canal line might be given the required fall per mile.

24. Surveys for Reservoirs.—In making surveys of reservoirs for storage of water for city water-supply or for irrigation and similar purposes, the scale and contour interval depend necessarily on the dimensions of the reservoir. The former should be from 400 to 1000 feet to the inch, and the latter from 2 to 5 feet vertical interval. Special surveys should be made of possible sites for dams and waste-weirs on larger scales and with a contour interval of 1 or 2 feet, and several cross-sections of the dam site should be run and the topography taken in detail for a sufficient distance above and below the center line. If sufficient borings or trial-pits are sunk, a contour map of the foundation material may be constructed.

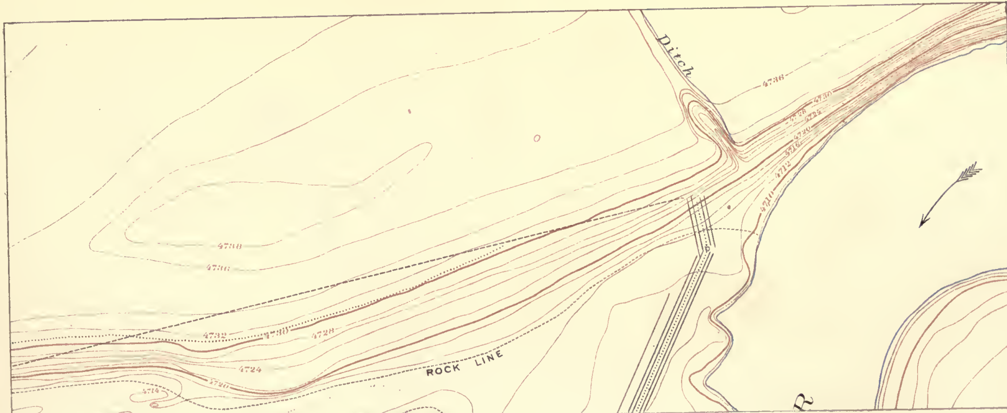
Perhaps the most satisfactory manner of making surveys of reservoir sites is instanced in the following practical example of one made by the author. A standard or base transit (Art. 87) and level (Art. 129) line is first run across the dam site, carrying the same a little above the highest possible flow line of the reservoir. From this should start a main transit and level line which should follow up the lowest or drainage line of the reservoir basin (Fig. 11, *A*, *D*, *G*), and this should be extended until it reaches an elevation corresponding to that of the highest probable flow line of the dam. Bench-marks (Art. 135) should be left as this line progresses, and stadia distances measured (Art. 102), and level elevations taken to points within the range of the level-telescope, as at *A*, *B*, etc. Based on this main transit and level line, a plane-table and stadia line (Art. 101), accompanied by spirit-leveling, should be run from the highest flow line of the dam cross-section around the corresponding contour line

on one side of the reservoir, *H*, *I*, *J*, etc., and if the land be clear, stadia and level sights may be taken to the other contour lines within the range of the instrument, including sights on lines of equal elevation on the opposite side of the reservoir if the latter be small. If large, however, a number of flags may be located on the opposite side by triangulation (Art. 73) or by stadia observations, and cross-section lines be run to these, from which the data for constructing a contour topographic map can be obtained as at *I* and *L*.

Another example of a reservoir survey is illustrated in Fig. 12, which is a portion of the map of the Jerome Park reservoir site in the city of New York, and was platted on a scale of 400 feet to the inch with a contour interval of 10 feet. From such a map it is possible to compute the contents of a reservoir for each additional five feet of elevation, and on it land lines and property lines are shown in such manner as to indicate the damage which will be done by submergence.

25. Survey of Dam Site.—A typical illustration of the topographic map resulting from the survey of a site for a *dam for* closing a *storage reservoir* is shown in Fig. 13. This survey was executed with a plane-table (Art. 73), chain (Art. 99), and spirit-level (Art. 129) on a field scale of 400 feet to 1 inch, with a contour interval of 2 feet. The result of such a topographic survey is to indicate clearly the best alignment for the dam, providing the borings which must necessarily follow the selection of such alignment prove its feasibility.

An example of a topographic survey executed for selection of a site for a weir or *diversion dam in a river* is that illustrated in Pl. III. This shows the topography of the flood-bed of the Snake River between its high bluff banks, as well as the contouring of the bed of the river as shown by soundings. On this is indicated the best alignment for the diversion weir as well as for the canal head and headworks. The field work of the survey was executed with transit,



A. J. WILEY. ASST. ENGINEER

1889

Scale 200 feet to 1 inch

PLATE II.—CONTOUR TOPOGRAPHIC SURVEY OF SITE FOR DIVERSION DAM, SNAKE RIVER, IDAHO.